

Technical News Briefs

NBS Technical Developments

NEW 10-FOLD QUASICRYSTAL STRUCTURE FOUND

A new type of quasicrystal structure has been found at the National Bureau of Standards (NBS) by NBS scientists and guest workers from Johns Hopkins University. The 10-fold (decagonal) quasicrystal is a totally different kind of aperiodic crystal from the first one of its kind discovered at NBS three years ago by a guest worker [1] from the Israel Institute of Technology.

The present discovery [2] proves that other types of nonperiodic crystal structures exist and can be made in materials. The 10-fold crystal structure was found in an alloy of aluminum and manganese produced by the same melt spinning technique to rapidly solidify metals that Shechtman used when he found icosahedral symmetry (six intersecting 5-fold axes) in a related alloy.

The crystal structures in these alloys defy a 100-year old theory in crystallography that is based on the assumption of periodicity, which requires all crystal structures to have only 2-, 3-, 4-, and 6-fold symmetry axes in various combinations to fit in one or another of the 32 classical diffraction pattern symmetries. Icosahedral and decagonal symmetry do not fit in these rotational patterns and therefore cannot be periodic. They belong to a new classification of crystals that have quasiperiodicity and are called "quasicrystals." Bendersky's 10-fold crystal is periodic along one axis and quasiperiodic along the other two; Shechtman's alloy is quasiperiodic in all directions.

Until Shechtman's discovery, there had been no exceptions to the theory and all crystals conformed to the 32 symmetries. Without this restric-

tion of periodicity in crystal structures the number of possible symmetries is infinite.

References

- [1] Shechtman, D.; I. Blech, D. Gratias, and J. Cahn, Metallic phase with long-range orientational order and no translational symmetry, *Phys. Rev. Ltrs.*, Vol. 53, 1951-1954 (1984).
- [2] Bendersky, L., Quasicrystal with one-dimensional translational symmetry and a 10-fold rotational axis, *Phys. Rev. Ltrs.* Vol. 55, 1461-1464 (1985).

BOND ENERGY VALUES IN SIMPLE HYDROCARBONS INCREASED

The values for the energies of the primary, secondary, and tertiary C-H bonds, which for nearly 40 years have been accepted to be 410 ± 4 , 397 ± 4 , and -385 ± 8 kJ/mol, respectively, have been revised upwards by recent work at NBS. The new values for the bond energies are 422 ± 2 , 414 ± 2 , and 402 ± 2 kJ/mol.

Bond energies are basic quantities for any general theory of chemical reactivity, and are needed for the modelling of any complex chemical processes such as high temperature pyrolysis or oxidation. The revised values for the C-H bond energies are a major step towards obtaining a complete understanding of the hydrocarbon cracking problem in terms of elementary chemical reactions.

The revisions result from a critical evaluation of data on elementary chemical kinetic processes. The work, supported by the Basic Energy Sciences Division of the Department of Energy, is aimed at the development of a data base of elementary kinetic processes for the computer simulation of combustion-related phenomena.

Because the rate constants of elementary chemical reactions are crucially dependent on reaction energetics, chemical kineticists are able to

infer bond energies from rate constants. Although the previously accepted values for C-H bond dissociation energies were derived from experimental methodologies now known to be deficient, work in the 1960's led to results which appeared to support those values. However, in recent years, there has been a gradual accumulation of rate constant data which differed by 1 to 3 orders of magnitude from predictions based on the accepted values of the bond dissociation energies. Since these results are usually assessed individually, the discrepancies have usually been dismissed as the effects of unknown experimental artifacts.

The NBS effort [1] involved a critical examination of these previously rejected results on the rate constants of alkane and alkyl radical decomposition processes. Although these data were in gross disagreement with the values which would be expected on the basis of the accepted thermodynamics of the processes and the well-established kinetics of the reverse combination reactions, it was found that none of the measurements could be rejected. The next step was to establish thermodynamic self-consistency as a requirement for the data base, in order that the second law of thermodynamics should not be violated. Using recent theoretical and experimental entropy data, the NBS effort then demonstrated that the extensive body of rate data did lead to internally-consistent higher values for the bond dissociation energies.

The proposed new values for the bond energies make possible the resolution of many controversies in the chemical literature. For example, use of the previously accepted bond energy values led to a prediction that there should be an energy barrier for certain di-radical recombination processes (for example, ring closure of a tetramethylene species to give cyclobutane), but theoreticians had never been able to reproduce such a barrier. The revised bond energy values remove the predicted barrier. Using the new values, the rate data for alkane-alkyl radical systems now show the systematic trends which would be predicted by any reasonable theoretical model. Therefore, the results of this critical data evaluation can be considered to be a validation of the kinetic methodologies for the determination of molecular stabilities.

The NBS work demonstrates the contribution that data evaluation within a proper theoretical framework can make toward a fundamental understanding of physico-chemical problems. In particular, the work demonstrated the importance of distinguishing between errors of measurement and errors of interpretation.

References

- [1] Tsang, W., The stability of alkyl radicals, *J. Am. Chem. Soc.* 107, 2872-2880 (1985).

NBS RESEARCHER DEVELOPS PARAMETRIC ELECTROMETER TO IMPROVE CHEMICAL ANALYSIS

Scientists who use mass spectrometers to perform medical, environmental, or industrial analyses at low concentrations—parts per million or below—should find a new device helpful in improving their measurement systems. Called a parametric electrometer, the invention was designed to measure extremely low levels of electrical current through the computer-controlled data collection systems of mass spectrometers. The device is an improvement over existing models because of its ability to measure signals at levels close to the theoretical limit of noise. It features variable response times at the flick of a switch, allowing an operator to control response time and noise level, two important factors in performing a mass spectrometric analysis at low levels. Though the electrometer was designed for use with NBS-developed thermal ionization mass spectrometers, it may be used with other similar types of instruments and measurement systems.

For further information contact Ronald W. Shideler, National Bureau of Standards, Gaithersburg, MD 20899.

FIRST NEUTRON OBSERVATION OF MAGNETISM IN A MULTILAYER MATERIAL

NBS scientists in collaboration with colleagues from the University of Illinois, have performed the first neutron-scattering study [1] of the magnetic order in a epitaxial multilayer of the rare earth metals dysprosium (Dy) and yttrium (Y). Multilayers are a very new class of materials which are prepared by molecular beam epitaxy techniques and consist of single-crystal layers of magnetic Dy and non-magnetic Y, each only 40 angstroms thick and stacked 64 bilayers high. These novel materials, combined with the unique probe of magnetic neutron scattering, have enabled the determination of the remarkable result that the helical magnetic order in the Dy layers is propagated through the intervening Y layer and into the next Dy layer without loss of phase coherence.

The neutron experiments allowed details of the helical magnetic order and its range, which was greater than 5 bilayers, to be examined directly in a manner not possible with conventional techniques.

These results are a dramatic confirmation, not previously available for ordinary alloy systems, of the existence of a peak in the generalized susceptibility of metallic yttrium at a wavelength close to that of the helical ordering found in other rare earth metals. These results have significant implications on the tailoring of such layered structures for specific magnetic applications.

References

- [1] Falamon, M. B.; S. Simha, J. J. Rhyne, J. E. Cunningham, R. W. Erwin, J. Borders, and C. P. Flynn, Long-range incommensurate magnetic order in a Dy-y multilayer, Phys. Rev. Lett., Vol. 56, 259-262 (1986).

COMPOSITIONAL MAPPING: QUANTITATIVE ELECTRON MICROPROBE IMAGING DEVELOPED

Techniques to produce the first fully quantitative *compositional images with micrometer spatial detail* by means of the electron probe microanalyzer have been developed [1,2]. The imaging techniques involve the acquisition of digital images based upon direct measurement of x-ray counts at each pixel in an image. The full quantitative analysis procedure which is normally employed for analysis at individual points is then applied at each pixel in the scan, including correction for detector dead-time, background, spectrometer, defocussing, standardization, and matrix correction. The resulting images consist of quantitative compositional values which have equivalent accuracy and precision to conventional single-point analyses. Techniques have also been developed for quantitative display of these compositional images. The most successful technique has been the use of color encoding based on the so-called "thermal color" scale, in which the sequence of colors assigned to the intensity scale is that which is observed when an object is heated: various shades of red, orange, yellow, and white. Such encoding provides an intuitive scale in which the position in the color sequence is proportional to the sensation which the human eye receives. With this scale, concentrations ranging from 0.1 to 10 weight percent have been successfully displayed in a single image. The first application of the digital compositional mapping technique has been in the study of diffusion-induced grain boundary migration in polycrystalline binary alloys. In this application, zinc distributions with concentrations as low as 0.1 weight percent were mapped with micrometer spatial resolution at grain boundaries in polycrystalline copper.

References

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- [2] Newbury, D. E.; D. S. Bright, D. Williams, C. M. Sung, T. Page, and J. Ness, Application of digital SIMS imaging to light element and trace element mapping. In: Secondary ion mass spectrometry, 5, Springer-Verlag, Berlin (1986).

NON-TOXIC "NATURAL" BONE CEMENT DEVELOPED BY DENTAL SCIENTISTS

A new calcium phosphate cement for the repair of teeth and bone that is *wholly compatible with living tissues in the body* has been developed by dental scientists at NBS. Researchers from the Paffenbarger Research Center (PRC) of the American Dental Health Foundation at the bureau have developed the cement as a part of the PRC research program to study calcium compounds for use in dental treatments. The new material, which can be described as a "natural cement" because of its biocompatibility, is based on a mixture of two calcium phosphates, tetracalcium phosphate and brushite [1]. When the two compounds are combined they form hydroxyapatite, the primary mineral in teeth and bone. Laboratory studies by the American Dental Association (ADA) in Chicago confirm the cement's biocompatibility with soft and hard body tissues, and the ADA reports there is no toxic reaction. Laboratory research also shows that because of the new cement's setting properties, the material has significant potential use in a wide variety of dental treatments and in other health care applications. In dentistry, the cement may be used as a base for dental fillings, as a filler for root canals, as a desensitizing agent for the roots of exposed teeth, and as a filler in bone sockets after tooth extraction. Preliminary studies also indicate that the new material *may have use as a bone cement to set prosthetic knee and hip implant devices*. The scientists report it will be at least two years before clinical studies on some of the cement's dental applications are completed and the material is available to dentists. It probably will be five years before the cement is approved for use in medicine.

References

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International Comparisons of National Standards

U.S. AGREES WITH ITALY AND AUSTRALIA TO RECOGNIZE THE EQUIVALENCE OF EACH OTHER'S NATIONAL STANDARDS FOR THE SIX BASE UNITS OF THE SI SYS- TEM.

In signing ceremonies in October 1985, the NBS Director, Dr. Ambler, ratified an agreement with the Istituto Elettrotecnico Nazionale "Galileo Ferraris" of Italy to recognize the calibrations in length and temperature done by either institution as valid in the other country. The agreement is to facilitate the sale of products between the two countries.

In a similar ceremony in Gaithersburg, MD, NBS signed an agreement with the National Measurement Laboratory of the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) to recognize the equivalence of the national standards for the six base units of the SI system.

Both Italy and Australia are signatories to the Convention of the Meter and determine, like the U.S., their basic units of measurements in accordance with the definitions for SI units adopted by the General Conference of Weights and Measures, an intergovernmental body that is the recognized world authority on physical quantities and the way they are measured.

COLLABORATION IN ELECTROLYTIC CON- DUCTANCE STANDARDS WITH HUNGARY

Hungarian electrolytic conductance standards were recently compared with those maintained at NBS by the Inorganic Analytical Research Division. Mrs. Anna Tomek from the National Office of Measures (OMH) in Budapest, Hungary, spent three weeks at the NBS Conductance Facility to confirm the compatibility of the two nations' measurement systems in this important field. Further intercomparisons will be conducted when NBS issues a Standard Reference Material for electrolytic conductivity. The collaboration between NBS and OMH continues as research is conducted into improving the accuracy of electrolytic conductivity measurements and standards and this work complements the effort in standardization of pH measurements that was begun last year between NBS and OMH.

For further information contact William F. Koch, National Bureau of Standards, Gaithersburg, MD 20899.

INTERNATIONAL COMPARISON OF CLOCKS

This past year NBS scientists in Boulder, CO succeeded in comparing two clocks thousands of miles apart with an accuracy that amounts to one second in the course of a million years. David W. Allan achieved the most accurate clock comparison across the Pacific with colleagues at the Radio Research Laboratory in Tokyo. They checked the U.S. primary standard in Boulder, CO against the Japanese primary standard. The intermediary was the U.S. Department of Defense's Global Positioning System (GPS) of navigation satellites with their on-board atomic clocks.

This intercomparison brings Japan into the community of nations that contribute to the definition of the international atomic second, thus making International Atomic Time still more accurate. Besides the U.S., other nations that contribute to the definition of the second are Canada and the Federal Republic of Germany.

As a result of this intercomparison, the National Aeronautics and Space Administration, and the scientific community will be able to obtain a better time reference for deep space probes and the investigation of pulsars, the still somewhat mysterious emitters of radio waves in the universe.

Most industrial nations use laboratory clocks based on the vibrations of cesium atoms as their national standards of time. Prior to the availability of access to the GPS, international comparisons had to be done with portable clocks carried between national laboratories. Now the comparison can be done quickly by reviewing an electromagnetic signal from a satellite that is in common view of both time laboratories.

For further information contact David W. Allan in Boulder, CO 80303.

New Services From NBS

BUREAU STARTS TELECOMMUNICATIONS TESTING SERVICES

NBS is establishing a voluntary laboratory accreditation program (LAP) for laboratories that perform electromagnetic compatibility and telecommunications equipment testing. The program was

requested by five commercial testing laboratories under new procedures of the National Voluntary Laboratory Accreditation Program. The companies believe accreditation will aid them in exporting their products to other countries. The LAP will provide national recognition to accredited laboratories that are capable of performing specific test methods for conducted emissions, radiated emissions, and terminal equipment compatibility in Federal Communications Commission (FCC) standards.

For further information on the LAP, or for an application package that includes a list of test methods, fee schedule and handbook, contact Harvey Berger, National Bureau of Standards, Gaithersburg, MD 20899.

NEW MAP FOR SPECTROPHOTOMETRIC TRANSMITTANCE

NBS has established a new Measurement Assurance Program (MAP) for laboratories measuring spectral transmittance [1]. The program makes it possible to check the absolute calibration of spectrophotometers against the NBS scale over a transmittance range of 0.92 to 0.001, as well as the wavelength accuracy of the spectrophotometers. MAPs are special calibration programs developed by NBS that make it possible to evaluate the entire measurement system and procedures of a participating laboratory, rather than simply the instruments used by that laboratory. The cost of the spectrophotometric transmittance MAP is \$1700.

References

- [1] Eckerle, K., *Transmittance MAP Service* (SP 692), U.S. Government Printing Office, Washington, DC 20402. (\$2 prepaid. Request stock no. 003-003-02655-7.)

For further information on this MAP contact Kenneth Eckerle.

NEW CALIBRATION SERVICES FOR USERS OF AIR NAVIGATION SYSTEMS

An airplane approaching an airport may accurately measure its direction of flight relative to magnetic north using VOR (Very-high-frequency Omni Direction Range) signals from ground based transmitters. The world wide VOR navigational system which has been in use since 1946, consists of more than 1000 ground based transmitters located near airports which broadcast a standardized signal which can be decoded by bearing-angle indicators aboard individual aircraft. NBS has recently developed a calibration service for bearing angle indicators and for the audio generators which are used to

modulate the VHF signals that are transmitted and provide the bearing angle information [1].

The new calibration service is based on two new instruments which have been designed and built at NBS; the first, a standard signal generator produces both a variable phase 30 Hz signal and a 9,960 Hz signal frequency modulated at 30 Hz which provides a reference phase. The estimated uncertainty of the phase difference (bearing angle) produced by this generator is $\pm 0.028^\circ$, approximately, a factor of 10 better than generators currently in use in operational VOR systems. The second instrument, a standard bearing angle indicator (phase meter) has the same estimated overall uncertainty, based upon tests made using instruments.

Bearing angle indicators may be calibrated at NBS using the standard signal generator. While in principle the NBS bearing angle indicator can be used to calibrate VOR signal generators most commercial generators cannot be calibrated directly, since the waveforms generated are not compatible with the requirements imposed in developing the NBS standards. However, generators may be calibrated indirectly by obtaining a calibration of a bearing angle indicator which may then be used as a transfer standard with only minor loss of accuracy.

References

- [1] Detailed information on the new calibration services may be obtained by contacting Neil T. Larson, Boulder, CO 80303. *VOR Calibration Services* (TN 1069), Stock Number 003-003-02652-2, the U.S. Government Printing Office, Washington, DC 20402 (price \$6.50).

NEW MEASUREMENT SERVICE ESTABLISHED WITH STANDARD BETA-PARTICLE BEAMS

NBS has established a measurement service with standard beams of ^{147}Pm , ^{204}Tl , and $^{90}\text{Sr} + ^{90}\text{Y}$. These are beta-particle sources with maximum energies of 0.2, 0.8, and 2.3 MeV, respectively. The beams have been standardized at certain fixed distances in terms of absorbed dose to water or tissue. The facility will be employed to calibrate user-owned beta-particle sources, to calibrate transfer instruments suitable for calibration of beta-particle sources, and to irradiate user-owned personnel dosimeters and other passive dosimeters to known levels of absorbed dose. Measurement-assurance tests are planned between NBS and other beta-particle calibration laboratories.

For further information contact J. S. Pruitt or M. Ehrlich, National Bureau of Standards, Gaithersburg, MD 20899.

New Standard Reference Materials*

MATERIALS AIMED AT BOOSTING ACCURACY OF LEAD-IN-BLOOD TESTS

To improve the reliability of blood tests for determining long-term exposure to lead, NBS has developed a Standard Reference Material (SRM) for calibrating the laboratory instruments that measure minute amounts of lead in blood. Wide-ranging results—some in error by as much as 200 percent—have been obtained in past studies when blood samples with known lead concentrations were sent to various clinical and analytical laboratories for analysis. Though analyses have improved in recent years due to refinements in technology and increased quality control, there is still a need for a lead-in-blood standard as a reference for checking instrument accuracy and analytical methods. The new SRM is issued to fill this need. It is available in units that each contain four bottles of varying lead concentrations in porcine (pig) blood: 5.7, 30.5, 49.4, and 73.2 micrograms per deciliter.

For technical information contact D. Reeder.

STANDARD REFERENCE MATERIAL FOR BETTER BREATH AND BLOOD ALCOHOL MEASUREMENTS

Ensuring accuracy in the instruments law enforcement agencies use to measure alcohol content in breath and blood is NBS' goal in producing a SRM that is now available. Called Ethanol-Water Solutions, the SRM was developed after law enforcement agencies requested an NBS alcohol/water reference material be produced that could be cited in court as a reliable standard for gauging breath or blood alcohol concentration. (Courts in some states and localities require validation of measurement techniques in drunk-driving cases.) The SRM can be used to calibrate and standardize alcohol-measuring equipment as well as to evaluate the daily laboratory reference solutions used in alcohol determinations [1,2,3]. SRM 1828 consists of five vials of ethyl alcohol (ethanol)/water solutions certified for these percentages by weight: 95.629 0.2992 (two vials are included at this concentration, and 0.1487 (two vials).

References

- [1] Diamondstone, B. I., Performance standard for calibrating units for breath alcohol testers, Federal Register, Vol. 40, No. 161, August 19, 1975.

- [2] Diamondstone, B. I., Standard for devices to measure breath alcohol, Federal Register, Vol. 38, No. 212, November 3, 1973.
- [3] Pella, P. A., and B. I. Diamondstone, Stability of aqueous ethanol solutions stored in glass ampoules, J. Forensic Sci., Vol. 20, 537 (1975).

MADE-IN-SPACE POLYSTYRENE SPHERES ARE NEW NBS STANDARD REFERENCE MATERIAL

A new size primary particle standard is available from NBS. The Standard Reference Material, designated SRM 1960, is a suspension of 10 micrometer polystyrene spheres in water. Previously only .3 and 1 micrometer standards were available. The spheres are used for calibrating particle size measuring instruments and optical and electron microscopes.

The 10 micrometer size is especially useful because blood cells are approximately this same size and the accurate measurement of blood cell size is the basis for many medical diagnostic instruments. The accurate measurement of particles of this size is also necessary to implement a new air pollution standard which defines 10 micrometer particles as a cut off. The U.S. Pharmacopia is also developing a standard for pharmaceutical materials based on 10 micrometer size particles.

The spheres from SRM 1960 were grown aboard the space shuttle Challenger using a process developed for NASA by Lehigh University. It is very difficult to grow acceptable spherical particles larger than a few micrometers on earth. The process for growing spheres making use of the very low gravity during space flights results in more spherical and uniformly sized particles and much greater yield than particles of this size grown on earth. Because the process of growing the particles is time consuming, the time in space of five shuttle flights was required to obtain 10 micrometer spheres. The spheres are the first product manufactured in space.

The particles were provided by NASA to NBS for measurement and distribution. The NBS interest and expertise in micro-dimensional metrology was used to measure the diameter of the particles by a new technique developed specifically for the task. The new measurement technique is called "center distance finding." It is an optical technique related to array sizing [1]. The diameter measurements were also checked using electron microscope techniques developed by NBS for one micrometer spheres [2].

*SRMs can be ordered from the Office of Standard Reference Material, NBS, Gaithersburg, MD 20899, telephone 301-921-2045.

References

- [1] Hartman, A., Investigations in array sizing 2. The Kubitschek effect, *Powder Tech.*, **42**, 269-272 (1985).
- [2] Mulholland, G.; A. Hartman, G. Hembree, E. Marx, and T. Lettieri, Development of a one-micrometer-diameter particle size standard reference, *J. of Res. of the NBS*, **90**, 3-39 (1985).

HOLMIUM OXIDE SOLUTION WAVELENGTH STANDARD FROM 240 TO 650 NM

The NBS Office of Standard Reference Materials has issued SRM 2034, Holmium Oxide and Perchloric Acid Solutions for use as a wavelength standard. This SRM is intended to be used as a reference standard for verifying the accuracy of the wavelength scale of spectrophotometers in the ultraviolet and visible spectral region (240 to 650 nm).

SRM 2034 consists of a solution of 4 percent holmium oxide in 10 percent perchloric acid in a fused silica cuvette of a nominal light path of 10 mm that fits the sample compartment of conventional spectrophotometers. The cuvette has a filler neck that was flame sealed after the cuvette was filled with the holmium oxide solution. Measurements of spectral transmittance of the solutions [1] were made by means of a high-precision spectrophotometer over the wavelength range 200 nm to 680 nm. The wavelength scale accuracy of this instrument was verified by extensive measurements of mercury and deuterium emission lines.

The measurements of spectral transmittance of the holmium oxide solutions were made as a function of temperature, purity, concentration, and spectral bandwidth. Analysis of the uncertainties associated with these parameters and the uncertainties associated with the calibration of the instrument wavelength scale and the data analysis have resulted in an estimated uncertainty of ± 0.1 nm for the determination of the wavelengths of minimum transmittance of the holmium oxide solution.

The certificate issued with SRM 2034 provides instructions for its use. The full details of the preparation, certification, and use of this SRM are described in NBS Special Publication 260-102. *Holmium Oxide Solution Wavelength Standard from 240 to 650 nm*.

References

- [1] Weidner, V. R.; R. Mavrodineanu, K. D. Mielenz, R. A. Velapoldi, K. L. Eckerle, and B. Adams, Spectral transmittance characteristics of holmium oxide in perchloric acid, *J. Res. of the NBS*, **90** (2), 115-125 (1985).
- [2] NBS Special Publication 260-102, *Holmium Oxide Solution Wavelength Standard from 240 to 650 nm*.

New Standard Reference Data

STEAM GROUP ISSUES NEW STANDARDS FOR PLANT DESIGN/OPERATION

The International Association for the Properties of Steam (IAPS) has issued a new set of equations and formulations that will help scientists and engineers in designing power plants, specifying equipment, and describing the performance of boilers, turbines, and other equipment used to generate steam power worldwide. The new information was approved by IAPS representatives from eight of the world's leading industrial nations; the United States, Canada, Czechoslovakia, Federal Republic of Germany, France, Japan, the United Kingdom, and the U.S.S.R. The new equations and formulations are for use in predicting the thermal conductivity and viscosity of ordinary water in liquid and vapor, as well as in determining the surface tensions of heavy water. The group also released new "skeleton" tables for determining the specific volume and enthalpy of ordinary water and steam that include evaluated data at specific grid points over a wide range of temperatures (freezing point of water to 1000 degrees Celsius, and pressures from zero to 1 GPa (=10 kilobar).

To obtain copies of the new 1985 IAPS standards, contact Howard J. White, Jr., National Bureau of Standards, Gaithersburg, MD 20899.

COMPILATION OF MAGNETIC DIPOLE LINES

NBS has just completed the first compilation of all the atomic and ionic magnetic dipole (M1) lines that have been observed, along with all possible predicted values, arising from transitions within the $2p^n$ and $3p^n$ ground configurations [1] for $2 \leq Z \leq 42$. Such spectral lines, usually called "forbidden lines," have long been used for the analysis of astrophysical plasmas (measurement of temperature, abundances of elements, Doppler shifts, etc.) and have recently become important for similar diagnostics of fusion energy devices. Identifications of these lines have appeared in the astrophysical literature for the past 40 years and in many other journals since their discovery in tokamaks for the last 15 years. Magnetic dipole radiation is typically 1 million times weaker than ordinary light (electric dipole) and is usually seen only in density ($10^{13}/\text{cm}^3$) extended light sources such as the solar

corona, nebulae, and laboratory magnetically confined plasmas such as tokamaks. The latter is the principal machine designed to generate fusion energy. This radiation is of special importance because it is usually the only long wavelength radiation ($>2000 \text{ \AA}$) produced by highly ionized atoms. It may therefore, be conveniently observed through air.

This is the first compilation of its kind to include all atoms from Be to Mo and will serve both the astronomical and laboratory plasma communities. The compilation contains 384 known lines and 1660 calculated wavelengths in the range of 100 A

(10 nm) to 26 nm. The calculated values are obtained from accurately known energy levels for Be to Ni and from semi-empirical calculations made for Cu to Mo that have led to the discovery of many more of these lines. Transition probabilities obtained mainly from relativistic calculations are included, as well as ionization energies for the radiating ions.

References

- [1] Kaufman, V., J. Sugar, Forbidden lines in $ns^2 n\ell^k$ ground configurations and $nsn\ell$ excited configurations of beryllium through molybdenum atoms and ions, Phys. Chem. Ref. Data **15**, 1986 (in press).